A Summary of Data Sources on Nutrient Loading and Removal in the Lower Mississippi River Subbasin
In fulfillment of EPA Grant MX965660

Lower Mississippi River Subbasin Committee on Hypoxia

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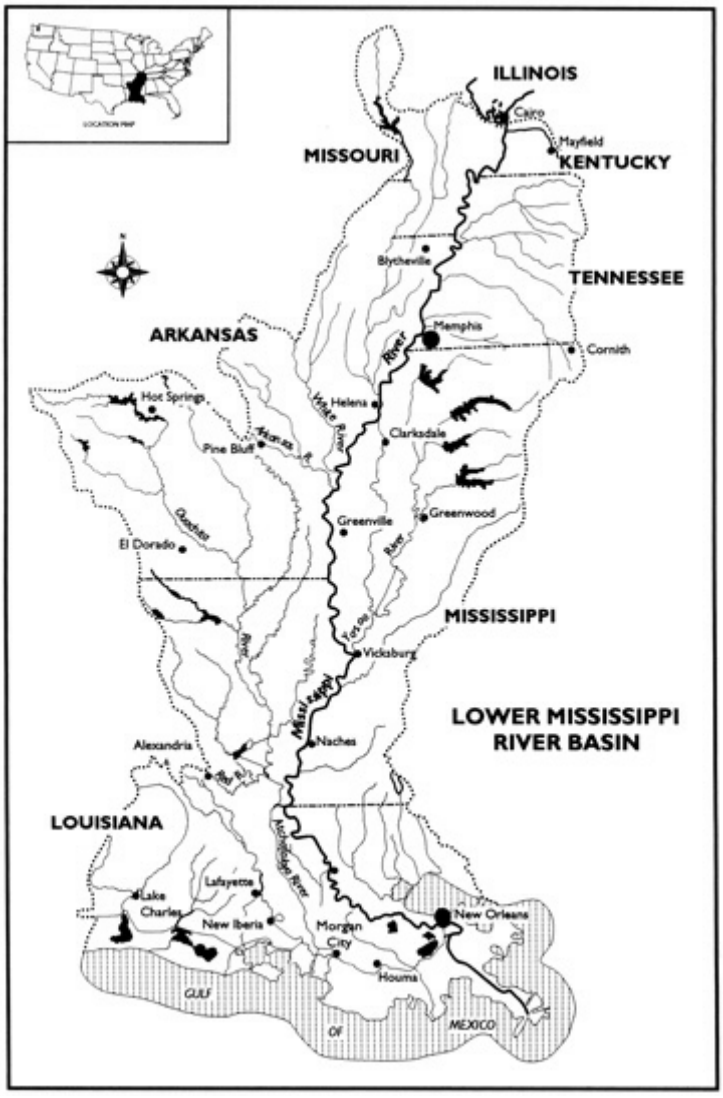

Arkansas Natural Resources Commission

101 East Capitol St., Suite 350

Little Rock, AR 722

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Introduction

This project is aimed at helping to meet two critical needs identified in the **Gulf Hypoxia Action Plan 2008**:

1) "Coordinate, consolidate, and improve access to data collected by State and Federal agencies on Gulf Hypoxia and Mississippi/Atchafalaya River Basin program activities and results;"

2) "Continue to reduce existing scientific uncertainties identified in the Science Advisory Board and MMR [Modeling, Monitoring, and Research] workgroup reports regarding source, fate, and transport of nitrogen and phosphorus in the surface waters of the Mississippi/Atchafalaya River Basin to continually improve the accuracy of management tools and efficacy of management strategies for nutrient reduction."[1]

Two key steps in this process will be the compilation of available regional data and its incorporation into local and basin-level decision-making processes. Recent models and reports have shown that while the largest inputs occur upstream, the Lower Mississippi River Sub-basin is a significant source of nutrient loading to the river (and Gulf), while also possessing important opportunities for nutrient uptake and removal.[2]

To aid the development of strategies in the Lower Mississippi River Basin that implement these opportunities, comprehensive information is needed on nutrient loading and uptake. Utilizing available data, strategies and plans can be developed based on the particular hydrology of the lower river basin - its major tributaries, agricultural and urban watersheds, remaining riverine floodplains, and the coastal distributary region. Expanded data collection, compilation, and integration across states will aid these efforts.

The "MMR Report," ***A Science Strategy to Support Management Decisions Related to Hypoxia in the Northern Gulf of Mexico and Excess Nutrients in the Mississippi River Basin*** (2004) noted that although annual basin-wide nutrient loads have been reported and monthly sampling occurs at the largest spatial scales, frequent sampling at all scales is critical to understanding nutrient sources, loadings and transport mechanisms, and sinks. The MMR Report proposed a monitoring framework of several levels, from the broadest (mainstem river), through major and smaller subbasins, down to the smallest (individual projects.)[3]

An ongoing compilation of existing data on current nutrient loading and reduction activities at all levels in the Lower Mississippi River Basin is needed to facilitate implementation of targeted nutrient reduction efforts/strategies.

This report summarizes and updates information on the following areas for the lower river basin:

Data sources on nutrient loading for tributaries and watersheds, major municipalities, and industrial sources;

Data sources and information on nutrient reduction activities and opportunities for their expansion;

Data sources on watershed and wetland protection and restoration efforts and their impacts on water quality;

Updated information on modeling and monitoring efforts.

Federal, state, local and private sources are included. Agencies have noted for some time the differences found between federal and state sources, along with gaps in some areas. Many states lack nutrient standards, most notably for the mainstem Mississippi River, while a number of states are developing nutrient criteria.

The geographic area of focus is that adopted by the Lower Mississippi River Sub-basin Committee on Hypoxia: the mainstem river, the Missouri Bootheel region, West Tennessee, the Arkansas, Louisiana, and Mississippi deltas, and the coastal plain and active deltas of the Mississippi and Atchafalaya Rivers.[4]

Basin-level Data and Information on the Mainstem Lower Mississippi and Atchafalaya Rivers

Basin-level studies generally divide the Mississippi River watershed into subbasins to determine nutrient loadings and calculate average annual fluxes. The 2007 report by the E.P.A. Science Advisory Board, ***Hypoxia in the Northern Gulf of Mexico***, took this approach, calculating the difference between upstream and downstream monitoring stations to get values for the Lower Mississippi River.[5]

Table 5: Average annual nutrient yields for the five large subbasins in the MARB for water years 2001-2005.

Subbasin	Nitrate-N	TKN	Total P
	(kg/ha/yr)		
Upper Mississippi	7.1	2.7	0.8
Ohio-Tennessee	6.4	3.3	1.1
Missouri	0.6	0.6	0.2
Arkansas-Red	0.5	0.8	0.1
Lower Mississippi	1.2	-0.5	0.9

Table 3: Average annual nutrient fluxes for the five large subbasins in the MARB for the 2001-2005 water years. (Percent of total basin flux shown in parentheses.)

Subbasin	Area (km^2)	Flow ($M\ m^3/yr$)	Nitrate-N	TKN	Total P
			(in 1,000 metric tons)		
Upper Mississippi[1]	493,900	116,200	349 (43%)	136 (32%)	40.4 (26%)
Ohio-Tennessee	525,800	279,800	335 (41%)	175 (41%)	58.7 (38%)
Missouri	1,353,300	60,080	78.6 (9.8%)	83.8 (20%)	30.4 (20%)
Arkansas-Red	584,100	67,200	28.7 (3.5%)	43.9 (10%)	8.7 (6%)
Lower Mississippi[1]	183,200	129,550	22.1 (2.7%)	-8.4 (-2%)	16.1 (10%)

[1]Nutrient fluxes calculated by difference. Negative values occur where downstream site had a lower flux than upstream site, the result of either error in the flux estimates or a real net loss of nutrients within the subbasin (Aulenbach et al., 2007).

EPA Science Advisory Board Report (2007).

The SAB Report concluded that in-stream nitrogen removal in river networks is variable, but can be substantial. Utilizing the SPARROW model, the SAB Report found that estimates of annual in-stream removal in regional drainages of the Mississippi River Basin ranged from 20-55% for nitrogen, and 20-75% for phosphorus.[6]

In the Lower Mississippi River Subbasin, the White River removed the lowest percentage of nitrogen, while the Arkansas River removed the highest percentage of both nitrogen and phosphorus. The SAB concluded that these results of the SPARROW model reflected the effects of seasonal pulses, especially in the spring. Stream flow in the Mississippi and Atchafalaya Rivers is a key indicator of the size of the Gulf Hypoxic zone.

The U.S. Geological Survey (USGS) conducts ongoing monitoring and modeling efforts that provide most of the information about water quality and river dynamics in the lower Mississippi basin. A summary of those programs, reports, and studies follows.

Real-time Streamflow and Water Quality (Mississippi River Basin Discharge to the Gulf relies on monitors at three sites: the Mississippi River at Baton Rouge, La., the Atchafalaya River at Morgan City, La., and the Wax Lake Outlet of the Atchafalaya at Calumet, La.[7] The monitors provide real-time (every two hours) measurements of nitrate concentrations in the rivers, and are operated in cooperation with the National Oceanic and Atmospheric Administration (NOAA), Environmental Protection Agency (EPA), and Gulf of Mexico Program (GMPO.) The Baton Rouge site also monitors phosphate in the Mississippi River.

The USGS states that the data are provisional, and not screened for anomalous readings, but that combined with stream-discharge information, will allow researchers and managers to better quantify seasonal variations in nitrate flux in the rivers.

The state of Louisiana has conducted environmental monitoring on the Mississippi and

Atchafalaya Rivers for over 40 years. As many as seven monitoring stations were operated on the Mississippi from Lake Providence near the Arkansas border to Pointe A La Hache south of New Orleans. The remaining active stations are at St. Francisville, Plaquemine, and Belle Chasse (each for 42 years.) An active station remains on the Atchafalaya River at Morgan City. Twenty-five water quality parameters are monitored on a monthly basis at the active stations; historical records exist for the discontinued ones.[8]

On its "Hypoxia in the Gulf of Mexico" pages, USGS also includes current and previous data and estimates on nutrient flux and streamflow data for delivery from the Mississippi-Atchafalaya River Basin to the Gulf. ***Streamflow and Nutrient Flux of the Mississippi-Atchafalaya River Basin and Subbasins Through Water Year 2008*** includes the period of record through September of that year.[9] The stations used to calculate flow and flux are located on the mainstem of the Mississippi River or one of its major tributaries, but do not include any stations on the Mississippi below Thebes, Illinois. Stations at the Arkansas River below Little Rock and on the Red River at Alexandria, Louisiana provided data on loading to the lower Mississippi. The page provides spreadsheets on streamflow and nutrient flux estimates for five large subbasins, including the Lower Mississippi.

Streamflow and Nutrient Fluxes of the Mississippi-Atchafalaya River Basin and Subbasins for the Period of Record Through 2005 (USGS 2007-1080) provides streamflow figures and estimates of nutrient delivery (flux) to the Gulf of Mexico from the Atchafalaya River, the mainstem of the Mississippi, nine major subbasins (including the Lower Mississippi), and 21 selected subbasins.[10]

Average annual net nutrient fluxes are provided for 5-year intervals in the five large subbasins of the Mississippi-Atchafalaya system, including the Lower Mississippi. Stations were located downstream and/or upstream of the mouths of the subbasins. The Lower Mississippi and Ohio/Tennessee subbasins provide a proportionally larger amount of runoff relative to the size of their drainage because of high annual rainfall. While the Lower Mississippi is the smallest of the major subbasins, at only 5.8% of the total drainage area of the entire Mississippi-Atchafalaya River Basin (MARB), it has the largest "confidence intervals" in its flux data.[11]

The report concludes that this is a result of net fluxes being calculated as a combination of estimates from six stations, and because the resulting net fluxes are small compared to the component fluxes. These large intervals were thought to contribute to the variability observed in dissolved nitrite plus nitrate yields for the Lower Mississippi Subbasin, though its overall net nitrogen yields were similar to those for the entire MARB.

Trends in Nutrient and Sediment Concentrations and Loads in Major River Basins of the South Central United States, 1993-2004 analyzed nutrient and sediment data collected at 115 sites by federal and state agencies to determine trends in concentrations and loads for selected rivers and streams.[12] These included the Lower Mississippi, Arkansas, Red, and White Rivers, along with the Central and Gulf Plains. Trends observed in the study area for hydrology, nutrient loads, and implementation of best management practices (bmps) were compared to determine regional patterns. A secondary objective was the calculation of nutrient and sediment loads and yields to compare their delivery to the Gulf of Mexico by rivers in the study area.

Observed trends at most of the sites were influenced by a regional decrease in streamflow, which reflected three droughts during the study period, the most extreme of which was in 2000. The study reached the following conclusions:

For all nitrogen constituents analyzed, no trends were observed at half or more of the sites, and regional trend patterns for nitrogen could not be confirmed because of poor spatial representation of sites. Flow-adjusted concentrations of nitrite plus nitrate decreased at 7 sites and increased at 14 sites, while flow-adjusted concentrations of total nitrogen decreased at 2 sites and increased at 12 sites.

Notable increased trends in nitrite plus nitrate and total nitrogen at selected study sites were attributed to both point and nonpoint sources, while decline in ammonia concentrations at selected sites was attributed to improvements in municipal wastewater treatment facilities. There was no observed relation between increased trends in nitrogen in the study area streams and increased trends in population, and the study concluded that statistical results suggested increased trends in nitrogen could be related to increased commercial fertilizer use and/or land application of manure.

For “about 57%” of all phosphorus trend analyses attempted, no trends were observed or regional patterns confirmed because of poor spatial representation of sites. The study concluded that trends in population data were inversely related to trends in flow-adjusted phosphorus, and no relation was observed between phosphorus from fertilizer use and trends for either orthophosphorus or total phosphorus.

For both nitrogen and phosphorus, the Mississippi and Atchafalaya Rivers contributed the highest loads to the northwest Gulf of Mexico, but the yields from smaller rivers were similar or higher for both nutrients.

Most of the decreasing trends were observed on mainstem sites regulated with reservoirs, locks, dams, or other structures that restricted sediment from being transported downstream.

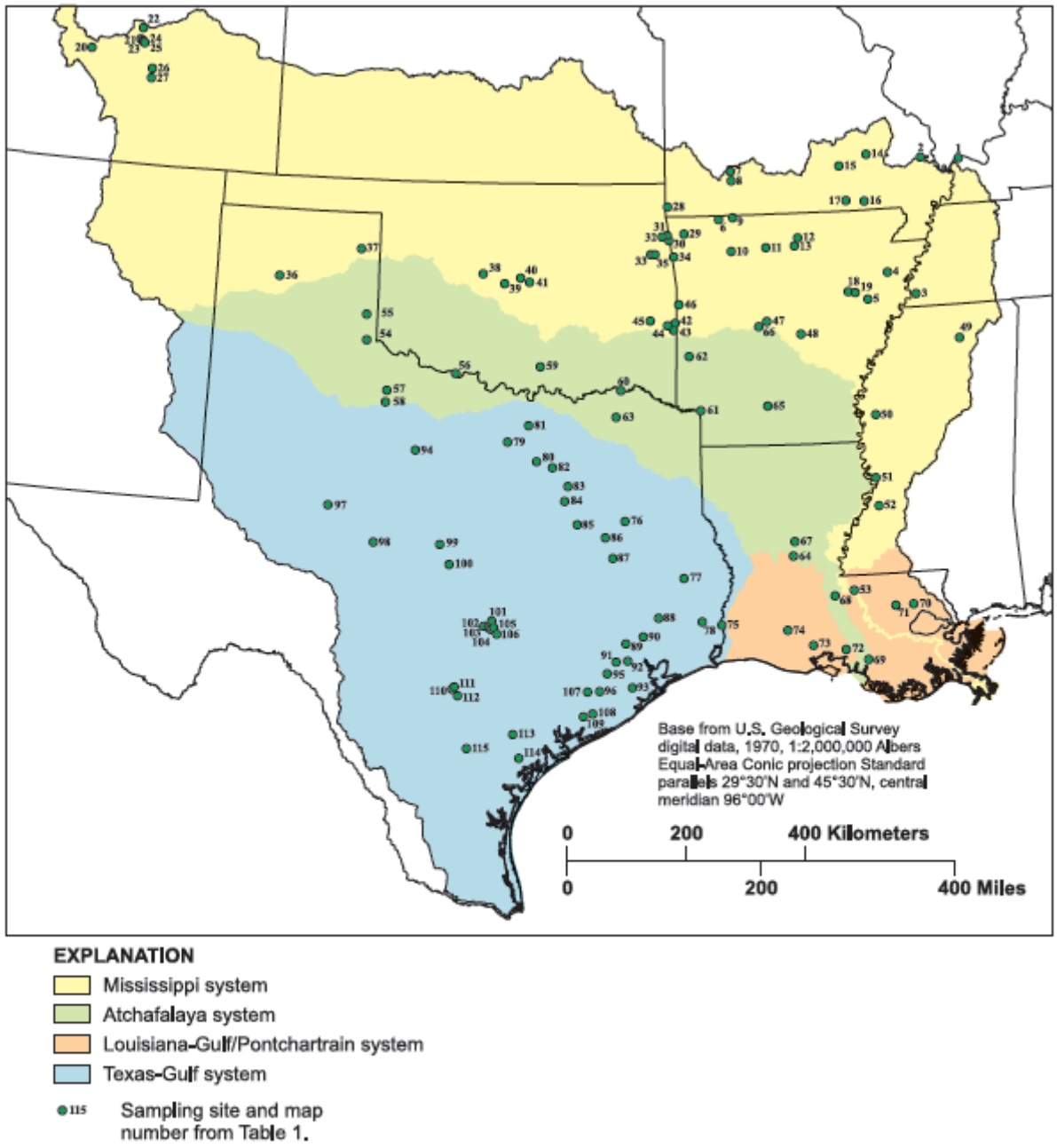


Figure 5. Sites selected for trend analyses and load calculations in the study area for the period, 1993-2004.

USGS, *Trends in Nutrient and Sediment Concentrations and Loads in Major River Basins of the South-Central U.S.* (2007).

Concentration of Selected Herbicides, Herbicide Degradation Products, and Nutrients in the Lower Mississippi River, Louisiana, April 1991 through December 2003 involved collection of water-quality samples from three sites in Louisiana: St. Francisville, Baton Rouge, and New Orleans.[13] Samples were analyzed for selected herbicides and nutrients (nitrogen, phosphorus, and silica) to determine their occurrence,

transport, and delivery to the Gulf of Mexico.

Researchers at USGS have also completed a number of reports such as ***Annual Dissolved Nitrite Plus Nitrate and Total Phosphorus Loads for the Susquehanna, St. Lawrence, Mississippi-Atchafalaya, and Columbia River Basins, 1968-2004***, that provide additional data for the lower mainstem river.[14] This report combined stream discharge data from the U.S. Army Corps of Engineers with discharge and water-quality data from USGS, and used LOADEST software to estimate dissolved nitrite plus nitrate and total phosphorus loads. Loads recorded at the Mississippi River at St. Francisville, La and the Atchafalaya River at Melville, La were combined to arrive at a total number for the MARB.

The USGS also conducts the *National Water-Quality Assessment (NAWQA)* Program, which collects chemical, biological, and physical water quality data from 51 basin study units across the U.S.[15] NAWQA is a major source of information for the Lower Mississippi River Basin, which falls within two study units, the Mississippi Embayment and the Acadian-Pontchartrain Drainages.[16] The program also maintains a Data Warehouse that allows clicks on a national map to find chemical concentrations in water bodies.[17]

Building on the assessment of the Upper Mississippi River carried out by the Environmental Monitoring and Assessment Program (EMAP) and Great River Ecosystems (GRE), an assessment of the Lower Mississippi River is being carried out by the U.S. Environmental Protection Agency (EPA) and mainstem river states as part of an overall National Rivers and Streams Assessment.[18] The lower river will be sampled from the Ohio River confluence to the Gulf of Mexico, utilizing 60 sites to obtain biological, chemical, and physical data, including nutrient concentrations, along with samples of phytoplankton, invertebrates, sediment, and contaminants.

Tributary Rivers, Streams, and Watersheds

The MMR Report noted that monitoring at different scales provides data critical to the understanding of processes that influence nutrient delivery and transportation within the Mississippi-Atchafalaya River Basin, but that not all monitoring at the four levels identified was not being coordinated sufficiently, with differences in time scales, variable protocols, and a lack of key parameters such as stream discharge data.[19]

While some discrepancies and gaps have continued, available data and indicators across states and watersheds in the Lower Mississippi River Basin can still be utilized to give a picture of nutrient processes and to aid subsequent coordination and refinement of monitoring efforts. The USGS *National Streamflow Information Program* (NSIP) utilizes a network of 7,500 stream gages to provide long-term, accurate information

aimed at meeting the needs of diverse user groups.[20] While these gages do not all record nutrient levels, some measure turbidity, and their annual reports can contain water quality data. The NAWQA Mississippi Embayment National Water-Quality Assessment Program utilizes 42 surface water collection sites on tributaries in Arkansas, Kentucky, Louisiana, Mississippi, Missouri, and Tennessee.[21]

The NAWQA Program has also undertaken several nutrient specific projects. The *Nutrients National Synthesis Project* combines information on nutrient enrichment and loading from rivers, streams, and aquifers, utilizing national data sets and case studies.[22] A study of the Effects of Nutrient Enrichment on Stream Ecosystems is focusing on agriculturally dominated landscapes.[23] One study unit in this project, the Ozark Plateau on the Missouri-Arkansas border, falls within the Lower Mississippi River Subbasin.[24] The USGS *National Water Information System* (NWIS) has Water Quality Data pages for each state, and samples grouped by county. [25]

Water quality data from across the country is also deposited in the **STORET** data management system maintained by the U.S. Environmental Protection Agency (EPA.) [26] STORET contains raw data on surface and groundwater collected by agencies, tribes, community groups, researchers, and others. Sampling results are accompanied by information on where and when they were gathered, and who sponsored the monitoring that did the collecting.

A major source of data and information on nutrient processes in the basin comes from the federal and state programs focused on impaired waters. These programs provide key information on the condition of rivers and streams that flow into the Mississippi and Atchafalaya Rivers and ultimately the Gulf of Mexico. Three sections of the Clean Water Act (CWA) are especially important in this respect.

Under Section 303(d), states are required to develop lists of impaired waters too polluted to meet water quality standards, and to develop Total Maximum Daily Loads (TMDLs) for pollutants. Section 305(b) requires states to report progress and status of water quality to Congress. Section 319 is a grant program that provides funds to states to carry out approved nonpoint source pollution reduction programs and projects. EPA maintains a number of interconnecting pages on its website to facilitate obtaining information about watersheds and Clean Water Act programs being implemented in them. Individual projects are also listed on state water program sites.

The *Assessment Database* (ADB) was developed to store information on state water body assessments, and to allow for analysis of both small stream segments and total watersheds.[27] Water bodies are assigned unique identification numbers based on the National Hydrology Database, with state abbreviation, Hydrological Unit Codes (HUC)

assigned by the USGS, and digits representing a specific reach or subdivision. The similarly named *National Assessment Database* summarizes water quality information submitted to EPA by states, and includes assessments of water bodies.[28]

The *Watershed Assessment, Tracking, and Environmental ResultS* (WATERS) Expert Query Tool is designed to facilitate specific queries on water quality listings, assessments, and information from the Clean Watershed Needs Surveys.[29] Utilization of the WATERS Query Tool requires specific information on the waters and watersheds involved, such as HUC codes and project names.

The *National Summary of Impaired Waters and TMDL Information* lists impaired waters by state, causes of impairments of 303(d) listed waters, cumulative TMDLs by pollutant, approved TMDLs by state, and the date of the latest impaired waters report utilized.[30] Impaired waters are listed by state, along with cause of impairment from 303(d) listings, approved TMDLs by state, and national figures on TMDLs. (State agency sites provide more current reports than some of those utilized on the EPA site.)

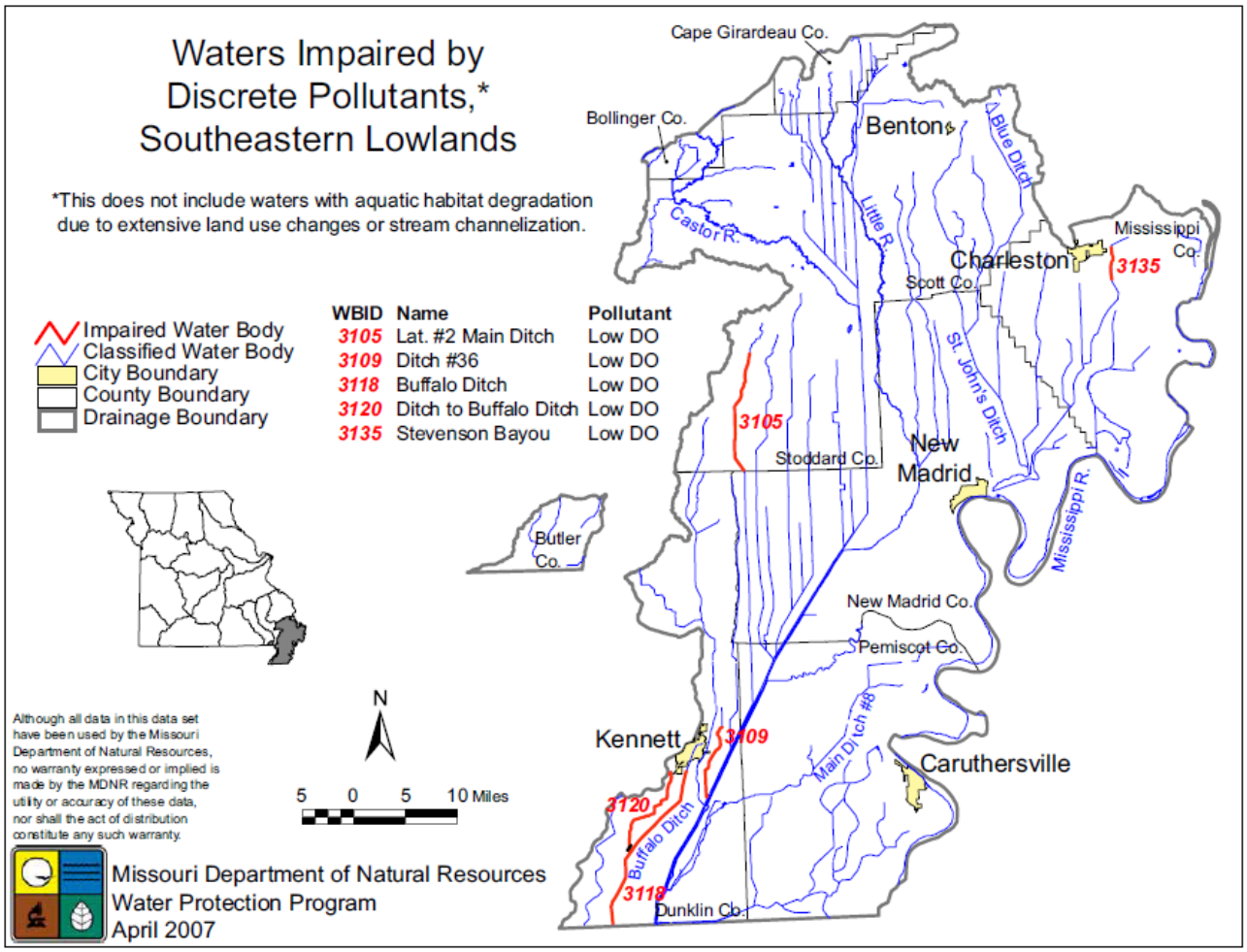
The *Water Quality Assessment Total Maximum Daily Loads Information Tracking and Implementation System* (ATTAINS) is a database of information reported by states under CWA Sections 303(d) and 305(b).[31] EPA specifies that because of differences in state assessment methods, information on the ATTAINS site should not be used to determine water quality trends or compare water quality conditions between states. Reports currently available on the page go up to 2006.

Some of the most up to date information on tributary rivers and streams is found on state water quality websites that describe ongoing programs and contain annual reports, which also generally include descriptions of their assessment methodologies and databases.

The state of Missouri's Department of Natural Resources Water Protection Program compiles Section 303(d) listings, the 305(b) Water Quality Report, Water Quality Standards, and TMDLs.[32] A Water Protection Map Gallery shows where listed waters are located.[33] The Proposed 303(d) List for 2008 is posted, along with a 2007 list approved by the state Clean Water Commission and a consolidated 2004-2006 Impaired Waters List approved by EPA.[34] Water Quality Data Information Sheets are provided for the water bodies proposed for listing, or delisting, along with a statistical analysis of the data and rationale for the recommendation.[35]

Missouri's 305(b) Water Quality Report shows the area commonly known as the "Bootheel" as the Southeastern Lowlands, with a number of streams affected by low dissolved oxygen (DO), a common problem for which nutrients are often a contributing factor.[36]

The Center for Applied Research and Environmental Systems (CARES) at the University of Missouri has developed a Watershed Evaluation and Comparison Tool to facilitate "watershed-based data visualization and assessment," which can generate watershed profiled, indicator reports for nutrient management, and watershed reference maps.[37] CARES also provides a hydrologic map page that allows searching Missouri's watersheds by 8-,11-, and 14-digit hydrologic units (HU).[38]



Missouri Water Quality 305(b) Report (2007).

Tennessee's Year 2008 303(d) List has a comprehensive grouping of water bodies across the state.[39] The state's 2006 305(b) Report provided profiles of Tennessee's watersheds.[40] The Tennessee Department of Environment & Conservation's Water Pollution Control Division has a webpage for the state's Watershed Management Plans, which include water quality assessment summary results and an inventory of point and nonpoint pollution sources. The water quality assessment includes data collection information from sites and surveys, and a summary of water quality and impairments.[41]

The Tennessee Department of Agriculture's Non-Point Source Program also supports monitoring projects under Section 319 of the CWA.[42] EPA-approved TMDLs are listed on a separate page on the TDEC Water Pollution Control site.[43] Tennessee designed its own Water Quality Database as an interim storage site prior to uploading data to STORET.[44]

The Water Division of the Arkansas Department of Environmental Quality (ADEQ) has a Reports and Data page that provides links to Water Quality reports, TMDLs, and other publications.[45] A link reaches a separate page with links to TMDLs that are completed and those out for public comment.[46] The state's *Integrated Water Quality Monitoring and Assessment Report* combines the required information for CWA Sections 305(b) and 303(d), and provides information on watersheds in the state's large river basins.[47]

A key source of information on water quality in Arkansas is the website *ArkansasWater.org*, which provides data, maps, and other resources on an up to date basis.[48] An interactive map allows viewers to click on a watershed, each of which has a page with background information that includes that system's impaired streams. Each watershed page also has links to federal sites (EPA, USGS), as well as a link to the Arkansas Watershed Information System developed by the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas.[49] A "Data, Models, & Maps" page on the ArkansasWater.org site has links to water quality and flow data from state and federal agencies, state and federal reports.[50]

The state of Mississippi's 303(d) list includes an atlas of monitored water bodies.[51] Mississippi's 305(b) Water Quality Reports are linked on the Department of Environmental Quality's (MDEQ) Surface Water Quality Assessment page, along with reports on some individual river basins, and a link to the TMDL Program page.[52] Among the state's river basins, the Mississippi Delta and the Yazoo Basin in particular have generated a large number of ongoing projects and studies which involve monitoring for nutrients and sediment,[53] although individual 305(b) reports have been done for several basins in the Lower Mississippi River Watershed, including the Big Black River (2002) and the South Independent Streams Basin (2000.)[54]

Louisiana's Department of Environmental Quality publishes a bi-annual Water Quality Integrated Report that combines reporting required by Sections 305(b) and 303(d),[55] while also publishing a Nonpoint Source Annual Report that summarizes progress on implementation of watershed plans and improvements in water quality.[56] The Mississippi River in Louisiana is cut off from most of its tributaries by levees. One major tributary, the Red River, flows into Louisiana at the divergence of the Atchafalaya and Mississippi Rivers.[57] The Red River, not a major source of nutrients, is commonly

grouped with the Arkansas and White Rivers in reports on water quality in the Mississippi River Basin. On the western side of the river in Louisiana, deltaic rivers and streams in the Ouachita River Basin drain into the Atchafalaya River, a branch of the Mississippi River that flows to the Gulf. On the eastern side, several small streams north of Baton Rouge mark the last tributaries that enter the Mississippi River.[58]

Distributaries of the Mississippi were cut off by levees in the 19th and 20th centuries, but there are projects being planned that would partially reconnect former distributary streams and create new "diversion" sites for river water.[59] The federal-state coastal restoration effort in Louisiana is reported on annually by participating agencies, but thus far water quality monitoring for most of these projects has not been carried out on a comprehensive, regular basis, and the central monitoring program, the Coastwide Reference Monitoring System (CRMS), focuses on other ecosystem function and structure aspects.[60]

States' Section 319 or Non-point Source Reports tend to focus on the status of projects. While this reporting presents information on implementation activities and other measures of progress, water quality data is not always included. Such data is available in some cases for watersheds with information from previous 303(d) listings and/or developed TMDLs, while particular projects may include data collection as part of their plan. One example is the Delta Irrigation Water Management project in the Missouri Bootheel, which calls for water and soil samples to be gathered on-site before and after irrigations to measure the movement of nitrogen below the root zone and off-field.[61]

Nutrient Loading and Removal Activities and Trends

Division by sectors – agriculture, wetlands, and point sources - provides a useful approach to summarizing data sources on nutrient loading and removal activities in the Lower Mississippi River Basin.

The *Management Action Review Team Report* (MART), released by the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force in 2006, compiled information on point sources of nutrients in the basin and on programs aimed at reducing non-point source nutrient pollution.[62]

The MART Report provided charts, graphs and maps to present programmatic information and statistics involving agricultural management practices, point sources, and wetlands. The broad application of agricultural conservation programs in the Lower Mississippi River Basin was evident through maps and acreage figures. These figures predated the subsequent expansion of crops for biofuel production throughout the basin, with substantial acres going back into production. There was a lack of information specific to the lower basin on nutrient sources such as combined sewer overflow.

Agriculture

The U.S. Department of Agriculture conducts several national-level data collection efforts.

The *National Agricultural Statistics Service* (NASS) organizes production data on a state basis, while the *Census of Agriculture* divides the country into Water Resource Regions, one of which is the Lower Mississippi.[63] 2009 marks the first time the Census' results were published at a watershed level (in the 2007 Census), using boundaries set by USGS studies. The HUC codes for major watersheds in the Lower Mississippi Water Resource Region are used to break down figures on crop production and land use.

The USDA Natural Resources Conservation Service (NRCS) carries out the *National Resources Inventory* (NRI), a statistical survey of trends in land use and natural resource conditions on non-federal lands, which collects data at hundreds of thousands of sample sites nationwide.[64] NRCS states that while the size of the sample enables the data to be used at many geographic levels (national, state, etc.), the NRI was not designed to provide statistical estimates for counties or 8-digit hydrological units. Users are recommended to consult technical guidance on the suitability and limitations of the data.

The 2003 NRI looked at Land Use, Soil Erosion, and Wetlands. Figures for Land Use and Soil Erosion were given for major river basins, which included the Lower Mississippi and the Arkansas-White-Red basins, which had 20.3 million and 33.3 million acres of cropland, respectively.[65] Water erosion rates recorded for the Lower Mississippi decreased from 433.1 million tons per year in 1982 to 246.1 million tons in 2003 (the Arkansas-Red-White basin went from 93.7 to 67.4 million tons over the same period.)[66] Wetlands recorded by the NRI were divided into "Non-federal land and water areas," with most of the Lower Mississippi Subbasin designated as "Delta States," with 17.9 million acres of palustrine and estuarine wetlands.[67]

Data from the NRI and other sources is utilized in the USDA Annual *Performance Results System* (PRS) Reports, which provide national-level information on conservation practices and systems, along with reports on state-level actions.[68] These include Conservation Systems Plans and Practices, such as land treatment, nutrient management, and wetlands, as well as program-specific reports. Performance measures by state do not always indicate which watersheds are involved, but Watershed or area-wide plans are also included in the reports (registration required for viewing.)

A USGS Report, ***County-Level Estimates of Nutrient Inputs to the Land Surface of the Conterminous United States***, ***1982-2001***, estimated nutrient input data for fertilizer use, livestock manure, and atmospheric deposition and allocated it to counties in the lower 48 states.[69] This project used NAWQA study units to delineate geographic areas and to

apply nationally consistent nutrient input data (the Lower Mississippi River Subbasin falls within the Mississippi Embayment and Acadian-Pontchartrain Drainage Units.)

Most of the data traditionally generated by USDA conservation programs like the Conservation Reserve (CRP),[70] Conservation Reserve Enhancement (CREP),[71] Wetlands Reserve (WRP),[72] and Environmental Quality Incentives Programs (EQIP)[73] has focused on enrollment acreage, investment, and participation, rather than water quality impacts. While acreage and expended funds are key indicators for programmatic implementation, there are expanded efforts underway to quantify environmental benefits (such as nutrient reduction) that such programs deliver.

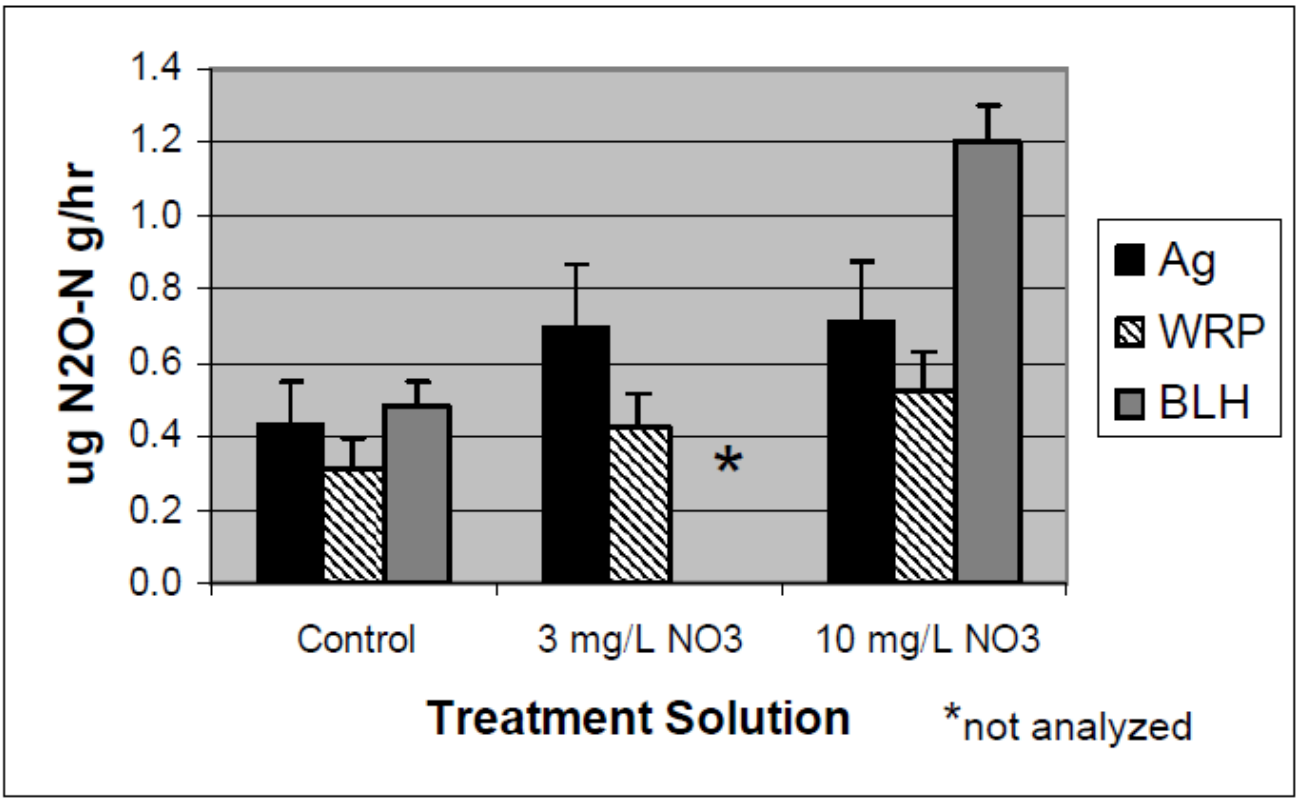
The *Conservation Effects Assessment Project (CEAP)* launched in 2003 is one of the largest efforts aimed at quantifying the environmental effects of conservation practices under USDA programs.[74] CEAP utilizes data collection and modeling in two of its three components, the National Assessment and Watershed Assessment Studies (the third component consists of bibliographies and reviews of current literature.) The CEAP National Assessment is broken down into four components: cropland, wetlands, wildlife, and grazing lands. The cropland component uses both sampling and modeling to arrive at benefit estimates for field-level and off-site water quality effects.[75] One of the forthcoming reports on the effects of conservation practices on cultivated cropland will focus on the Lower Mississippi River Basin.

CEAP's wetlands component has as one of its key goals the quantification of ecosystem services (such as pollution abatement) in agricultural landscapes, along with the knowledge base and gaps pertaining to the effects of conservation practices and programs on those services.[76] Studies are focused across eleven physiographic regions of the U.S., one of which is the Mississippi Alluvial Valley (MAV).

A USGS-led multi-agency study underway in the MAV involves some key wetland habitats of the lower river basin, located in the lower White/Cache River Basin in Arkansas and the Tensas River Basin in Louisiana.[77] An interim report on the project was published in 2008 that compares biochemical services such as nutrient and sediment reduction on cultivated, WRP, and bottomland hardwood sites.[78] A forthcoming study will utilize the Integrated Landscape Model (ILM) to quantify ecosystem services delivered by conservation practices in the Mississippi Alluvial Valley.

"Wetlands in Agricultural Landscapes," a literature synthesis developed by the Water Quality Information Center at the National Agricultural Library for the wetlands component of CEAP, includes Mississippi Alluvial Wetlands as one of the regions covered, with 56 entries.[79] A state-level report, looking at Missouri Wetlands Reserve Program easement monitoring data, has also been released.[80]

Figure 5. Soil denitrification potentials for active crop land (AG), Wetland Reserve Program (WRP), and native forest (BLH) in the Tensas, LA and Lower White/Cache, AR River Basins.



USGS Interim CEAP Report on Ecological Services in the MAV, 2008.

The *Watershed Assessment Studies* section of CEAP involves in-depth case studies of small watersheds selected under three USDA branches: the Agricultural Research Service (ARS), Natural Resources Conservation Service (NRCS), and the Cooperative State Research, Education, and Extension Service (CSREES.)[81] The "benchmark watersheds" being studied by ARS include 3 in the Mississippi Delta (Beasley Lake, Goodwin Creek, and the Yalobusha River), as well as the Salt River in northeastern Missouri (a tributary of the Mississippi River.)[82] The CSREES Competitive Grant Watersheds include Goodwater Creek in northeastern Missouri and Lincoln Lake in northwestern Arkansas.[83]

The CEAP watershed assessment work has generated a new web-based data system – *STEWARDS* (Sustaining the Earth's Watersheds: Agricultural Research Data System) - to compile and organize information from the ARS research watersheds.[84] Climate, soil, water, and socioeconomic data will be compiled in the system to help analyze the effects of conservation practices. While CEAP is a national assessment effort, much of the data it is compiling is being collected at the watershed level. A number of other programs

carry out data collection at that level either as part of focused studies or programmatic activities.

In addition to its Benchmark Watershed work under CEAP, the USDA Agricultural Research Service (ARS) is conducting other watershed-level studies on water quality impacts from nutrients and sediments. A number of ongoing studies from the National Sedimentation Laboratory in Oxford, MS have focused on watersheds in the Yazoo River Basin (listed in Appendix on Background Papers and Studies.) The ARS Soil & Water Research Unit formerly housed at Louisiana State University carried on research focused on the open ditch/surface agricultural drainage systems common in the Lower Mississippi River Valley.[85] The Cabin Teele Watershed in northeast Louisiana was the site of much of this work (currently terminated), which indicated significant reductions in nitrogen loss from farm runoff using a combination of bmp's and wetlands.[86]

The *Conservation Security Program* (CSP) has worked through selected watersheds to provide a concentrated technical assistance program to willing farmers.[87] Nutrient management is one of the areas included in the 3 Tiers of stewardship plans under the program. A number of watersheds in the Lower Mississippi River Basin have been selected by the CSP: Little River Ditches in Arkansas/Missouri (2004),[88] Lower St. Francis River in Arkansas/Missouri (2005),[89] Lower White/Bayou Des Arc in Arkansas (2005),[90] Big Black River in Mississippi (2005),[91] Loosahatchie River in Tennessee (2005), Lower Arkansas River (2006),[92] Tensas River in Louisiana (2006),[93] and Upper White River/Village in Arkansas (2008.)[94]

ARS developed the MANAGE *Nutrient Loss Database for Agricultural Fields in the U.S.* to compile measured annual nitrogen and phosphorus load and concentration data with corresponding watershed characteristics from field-scale studies.[95] The database also provides a platform that allows user input of project-specific data.

USDA's Southern Region Water Quality Coordination Project has created a *Regional Nutrient Management Publications Database* featuring all available nutrient management publications developed by extension/land-grant university faculty in a 13-state Southern Region.[96] One of the key purposes is for states to use the database to support water resource protection programs at the regional level.[97]

Agricultural projects figure prominently in states' 319 Programs. Figures on programmatic implementation (generally in acreage) can be combined with water quality measurements to give an indication of the effects of 319 projects.[98] To cite one example, USDA implemented 34,315.40 acres in bmp's in the Louisiana section of the Ouachita River Basin in 2005. Subsequent measurements of dissolved oxygen (DO) levels in several streams and rivers in the basin showed measurable levels of improvement.[99]

Wetlands

Despite having lost a substantial portion of its once immense natural floodplain, the Lower Mississippi River Basin contains some of the nation's largest areas of remaining wetlands, as well as some of the most extensive efforts at wetland protection and restoration. This activity is occurring at multiple scales, from creation of edge of field wetlands on farms to restoration of large areas of deltaic marsh close to the Gulf. Private and public efforts are focused on a variety of goals, one of which is general improvement in water quality. While water quality is not directly measured for many wetlands-related activities, their location and hydrologic connections, coupled with acreage figures, can provide an important indicator of current and potential water quality improvements.

The potential for expanding water quality monitoring for nutrient uptake levels is especially important for large scale private efforts being undertaken in the lower river basin by organizations such as The Nature Conservancy and Ducks Unlimited. The Nature Conservancy's Lower Mississippi River Program has identified a series of priority sites for protection and restoration from Missouri to Louisiana.[100] The Mississippi Alluvial Valley is a major area of focus for Ducks Unlimited, which has "Partners Programs" in lower river basin states.[101] These and other projects have combined wetland protection and restoration efforts with agricultural management practices like winter flooding of fields, which can improve water quality while enhancing habitat. Many of these projects are located near to the Mississippi and Atchafalaya Rivers or their tributaries, and are doubtless having a beneficial effect on water quality, including nutrient delivery to the Gulf.

The USGS-led *Lower Mississippi Valley Integrated Landscape Monitoring and Science Project*, working in conjunction with the CEAP assessment, is working to record land use changes and to quantify their impact on ecosystem services from systems such as wetlands.[102] Their studies have already quantified the differences in nutrient uptake between mature bottomland hardwood forests, recently planted or restored forests, and actively cultivated land in the lower basin.

Arkansas has a state Wetland Conservation Plan that has identified priority areas for protection and restoration, utilizing GIS and mapping techniques.[103] Three of the planning areas that have issued progress reports are located in tributary watersheds of the lower Mississippi River and would be prime areas for studying nutrient reduction potential: Bayou Meto, Bayou Bartholomew, and the St. Francis River. The Center for Advance Spatial Technologies (CAST) Center at the University of Arkansas has developed an Arkansas Wetland Resource Information Management System, which can

aid in analysis of wetland planning areas and of wetland status and trends in the state.[104]

A number of projects in different states are reconnecting the Mississippi River to sections of its floodplain. A WRP project in New Madrid County in Missouri returned a frequently flooded farm tract to wetlands, which fill when the river backs into the New Madrid Floodway during high water periods.[105] Wetlands are also key elements to broader watershed restoration efforts, such as those on the Obion River in west Tennessee, that are also trying to undo the effects of previous channelization of water bodies.[106] While it is known that these projects are delivering water quality benefits, many sponsors are not currently equipped to carry out regular monitoring or sampling to quantify them.

At the farm field level, programs such as CRP, WRP, etc. have resulted in hundreds of thousands of acres of wetlands being restored on agricultural lands in the lower river basin.[107] Some projects have focused specifically on measuring water quality improvements. A recent EPA-funded Wetland Program Development Project in Stoddard County in the Missouri Bootheel involved establishment of monitoring stations and collection of monthly water samples to measure natural filtering effects of wetlands restored in an area with a number of water bodies listed as impaired for DO or sediment.

There are also a number of studies underway to help clarify the capacity of coastal and deltaic wetland areas and habitats for nutrient assimilation. At a large scale, the nutrient retention capacity of the Atchafalaya River Basin, which contains the largest freshwater swamp in North America, and coastal wetlands near the active Mississippi River Delta, are areas of ongoing study. Both of these areas have had their hydrology altered extensively (see appendix on background papers.) The Atchafalaya River has an actively prograding delta, but much of its interior flow has been channeled or blocked by sedimentation, while levees separate the Mississippi River from its traditional floodplain from Baton Rouge to Head of Passes.[108]

The USGS *Atchafalaya and Mississippi River Deltas Study* includes nutrients among the environmental contaminants whose storage and delivery it studies.[109] The pairing of these deltas reflects the fact that they are part of the same river system but process their nutrient loads very differently. While the study looks at river- and shelf sediments as the “controlling mechanism” for fluvial delivery of contaminants to the Gulf, their records also help indicate the degree to which deltaic wetlands are currently filtering the system’s nutrient load.

Point Source/Industrial/Municipal

The second section of the MART Report released by the Mississippi River/Gulf of Mexico Nutrient Task Force in 2006 was a ***Reassessment of Point Source Nutrient Mass Loadings to the Mississippi River Basin***.[110] The point source nutrient loading data for this report came from EPA's Permit Compliance System database, which provides information on companies who have been issued permits to discharge wastewater into rivers.[111] The report found the Lower Mississippi to be contributing 22.3% of the annual point source mass loading of total nitrogen (TN), and 14.7% for total phosphorus (TP), as well as 20.2% of biological oxygen demand (BOD) loading. (The Arkansas-Red-White accounted for 11.4% of TN, 14.7% of TP, and 17.6% of BOD loading, respectively.)[112]

The 2006 **Reassessment** was an update of the 1998 **Analysis of Point Source Nutrient Loadings in the Mississippi River System** by EPA, which was undertaken to support the Council on Environment and Resources (CENR) assessment of Gulf Hypoxia.[113] The 1998 study provided estimated annual nutrient discharges for total nitrogen and total phosphorus for point source facilities, and contained detailed flow and loadings information for industrial and municipal point source discharges.

The EPA ***SAB Report*** (2007) revised upwards the estimates of total point source contribution of nutrients to the entire Mississippi River Basin. By their estimate, the Lower Mississippi and Arkansas-Red-White subbasins each contribute 13% of total phosphorus point source flux (which includes annual and spring flux.)[114]

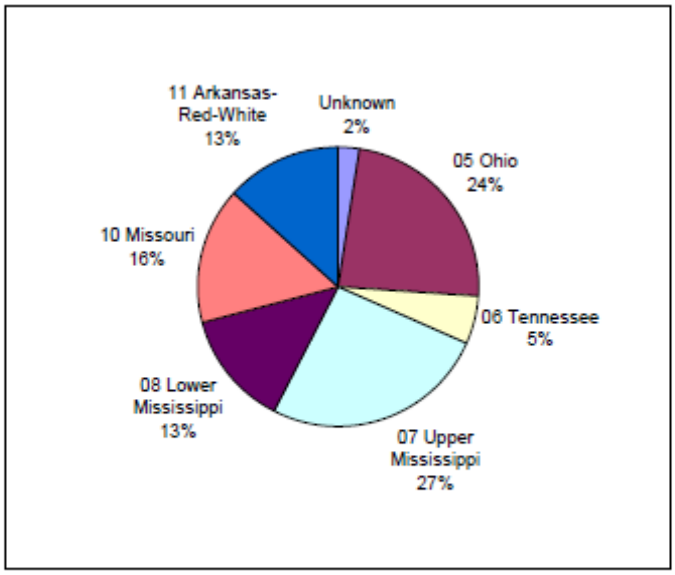


Figure 37: Total phosphorus point source fluxes as a percent of total flux for the MARB for 2004 hydrologic region.

A major source of information on point source loading to the Mississippi River and other water bodies is the *National Pollutant Discharge Elimination System* (NPDES) which is overseen by EPA.[115] As mandated by the Clean Water Act, NPDES regulates point sources, such as industrial, municipal, or other facilities that discharge directly into surface waters, by requiring them to obtain permits. All of the Lower Mississippi River states have been authorized by EPA to administer their own NPDES permit programs.

EPA's NPDES website provides links to authorized states' NPDES programs, as well as an *Envirofacts Warehouse*, which contains information on specific facilities with permits, and an "Enviromapper" showing their locations.[116] The site also provides a link to EPA's *Enforcement and Compliance History Online (ECHO)* of NPDES permitted facilities.[117] There is also a page for General and Individual Permit searches, which cover single or multiple facilities.[118]

The NPDES Program requires Municipal Separate Storm Sewer Systems (MS4s) to obtain a permit and develop a stormwater management plan.[119] Phase I of NPDES covered medium and large cities, or counties with populations of 100,000 or more. Phase II requires smaller municipal sewer systems to obtain a permit. EPA has created digitalized Urban Area Maps to assist states in developing Phase II municipal permits and programs, which can also serve as indicators of land use changes that can affect watersheds in the subbasin.[120]

The NPDES section on EPA's website also provides a page on States, with links to each state's NPDES program. Websites for state agencies administering NPDES also provide information on particular permits, such as those for large municipalities on the Mississippi river.[121] Such permits include monitoring parameters, such as wet weather and in-stream ambient monitoring, that include nutrients and can also serve as sources of data on nutrient loading in rivers and tributary streams.[122]

The "Environmental Leadership Program" coordinated by the Louisiana Department of Environmental Quality (LDEQ) specifically works to aid industries in the Mississippi River Industrial Corridor to reduce nutrient loading to the river.[123] Participating industries have provided figures on nutrient reductions achieved under the program.[124]

Atmospheric Deposition

The investigations contributing to the SPARROW report found that regional atmospheric deposition could account for 16-18% of the non-agricultural source of nitrogen to the Gulf, along with local deposition from power-plant and vehicular emission sources.[125] The SAB Report presented national data on the deposition of ammonia, nitrogen, and

phosphorus in the MARB,[126] and relied on the National Emissions Inventory (NEI) maintained by EPA.[127]

The NEI provides emissions trends data at the national and state levels, including emissions density maps for the U.S. The "Where You Live" page on the EPA NEI site supplies links to state and county emission summaries, as well as facility emissions information, where figures on emissions of ammonia, nitrogen, and phosphorus in states in the Lower Mississippi River Sub-basin can be found.[128] "On Road Vehicles" constituted the largest source of nitrogen oxide emissions in all LMR states except Louisiana, where they ranked behind "Non Road Equipment" and fossil fuel combustion.

Models

The MMR Report (2004) called for an integrated program of research and modeling to provide information on 3 areas:

1) nutrient cycling in terrestrial and aquatic ecosystems;
2) management activities/practices affecting nutrient sources, transport, and removal;
3) methods to refine existing models of 1 and 2, and to develop new integrated watershed models.

The MMR Report identified a number of existing modeling activities being conducted at small and large scales in the Mississippi River Basin, noting that much of the research and modeling is done at field- and plot-level and in small watersheds.[129]

The website of the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force provides a page with links to models used to evaluate nutrient loading.[130] Some of these, such as the AGNPS/AnnAGNPS model, have been used extensively in the Lower Mississippi Subbasin.

Agricultural Models

The National Water Management Center of NRCS has provided a webpage on "Model Description and Availability,"[131] as well as a page describing "Simulation Pollution Loading with Water Quality Models."[132] This page explains that "the advent of the interface between Geographical Information Systems (GIS) technology and water quality models has resulted in products such as the Hydrologic Unit Water Quality Tool (HUWQ), and provides the opportunity to blend field-level data with watershed-scale modeling technology." The Tensas River Basin in northeast Louisiana was selected to provide a test of the HUWQ Tool software.[133]

The *Agricultural Non-Point Source Pollution (AGNPS*) Model is designed to evaluate effects of management decisions on watershed systems.[134] In earlier versions, AGNPS was a "single event" model, but the current version is a system of modeling components that can be used with large watershed systems. The Missouri Department of Natural Resources has utilized AGNPS in its Special Area Land Treatment Program (SALT) to reduce agriculture-related pollution of rivers and streams.[135] (A partial listing of papers and studies on application of AGNPS in the lower river basin is provided in the Appendix.)

The *Soil and Water Assessment Tool (SWAT)* is a USDA-ARS computer model for predicting the effects of management actions yields of nutrients, pesticides, sediments, and water in large ungaged river basins.[136] SWAT is a public domain model supported by the USDA ARS Grassland, Soil, and Water Research Lab in Temple, Texas. SWAT technology enables it to subdivide larger basins into over 100 subbasins, and has specific components for nutrient loading.

The MANAGE (Measured Annual Nutrient loads from Agricultural Environments) Database is used with SWAT to compile measured annual nitrogen and phosphorus load data to represent field-scale transport from agricultural land. Only data published in peer-reviewed studies were included in MANAGE. Study locations in the Lower Mississippi River Subbasin include Keiser and Lincoln, Arkansas, Baton Rouge, Louisiana, and Holly Springs, Mississippi.[137]

The USDA CEAP Project issued a report on a *Model Simulation of Soil Loss, Nutrient Loss and Soil Organic Carbon Associated with Crop Production* aimed at identifying areas of the country most susceptible to nutrient and sediment loss and thus most likely to benefit from conservation practices.[138] The Lower Mississippi River Subbasin fell within the "South Central Region" of the study, which was found to have the second highest per-acre nitrogen loss, with an average 51 pounds per cropland acre per year. Total nitrogen loss in the region equaled 32% of annual N inputs.

While all nitrogen pathways in the South Central region were found to have significant losses (with the exceptions of windborne sediment and lateral subsurface flow), the highest losses were attributed to volatilization and dissolution of nitrogen in leachate. Peanuts and rice were the regional crops with the highest N loss rates. The dominant loss pathway for peanuts was leaching; for rice, surface water runoff. Rice had the highest loss for dissolved N in surface water runoff among all crops. The study also found high per-acre N loss for corn and soybean acres in the region.

Areas along the Lower Mississippi River were ranked as vulnerable for both nitrogen and phosphorus loss with waterborne sediment, but tended to have fewer localized areas

with the highest P loss estimates. The spatial distribution of phosphorus dissolved in surface runoff was found to be generally similar to that for nitrogen, with some important differences. Rice-growing areas in the Arkansas delta were highly vulnerable to N runoff, but less so for P. Rice-growing regions in southeast Texas and southern Louisiana had high levels of N and P loss dissolved in runoff.

Watershed and Nutrient Models

The Water Science and Technology section of EPA's website features a page on "Water Quality Models and Tools," with the goal of aiding use of models to perform both single-event and continuous simulations on catchments having storm sewers and natural drainage.[139] The EPA Center for Exposure Assessment Modeling (CEAM) distributes simulation models for surface waters, along with database software to quantify movement and concentration of contaminants.[140] Among these tools is the Environmental Fluid Dynamics Code (EFDC), a multifunctional surface water modeling system that has been used in water quality/eutrophication studies in the Yazoo River Basin.[141]

The *Spreadsheet Tool for Estimating Pollutant Load* (STEPL) model calculates nutrient and sediment loads from different land uses, as well as load reductions from use of best management practices.[142] STEPL can be used to calculate annual nutrient loads based on runoff volume and pollutant concentrations. The STEPL webpage provides a map linking to reports from selected watersheds in each state, including those in the Lower Mississippi River Subbasin, that show figures on land use, farm animals, septic systems, and hydrological grouping.[143]

EPA's Urban Watershed Management Research section provides a *Storm Water Management Model* (SWMM) for simulation of runoff quantity and quality from primarily urban areas.[144] In addition to modeling generation and transport of runoff flows, SWMM can estimate associated pollutant loads from runoff.

USGS's *Spatially-Referenced Regression On Watershed Attributes* (SPARROW) model has had major application for the Mississippi River Basin. A national-scale SPARROW model showing estimates for nutrient loading and transport in the Basin placed watersheds in rankings for nitrogen and phosphorus yields and delivery to the Gulf of Mexico.[145] The model included agricultural runoff and subsurface flow, urban sources, and atmospheric deposition of nitrogen in its nutrient sources. Calibrated models were used to predict mean annual flux and yield for TN and TP delivered to the Gulf by watersheds in eight regional drainages in the Mississippi-Atchafalaya River Basin (MARB).

The SPARROW report estimated delivered flux for the intervening combined drainage

of the Lower Mississippi and Atchafalaya watersheds as the difference between the delivered flux from all MARB outlets and the sum of delivered flux from upstream tributaries, including the Arkansas, Red, and White Rivers. It was assumed that the fraction of nutrients diverted to the Atchafalaya from the Lower Mississippi is identical to that known for stream flow (22 percent.)

The *System-wide Modeling, Assessment, and Restoration Technologies* (SMART) program developed by the U.S. Army Corps of Engineers Engineer Research and Development Center (ERDC) includes process descriptions for nutrient transport and ecological responses to nutrient management in its capacities, along with coupled hydrodynamic, transport, and ecological simulation models for large-scale applications to restoration decision-making. The project is also working to develop coupled or linked models for system-wide applications.[146]

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